Lift and Drag Control of NACA 23012 Airfoil Model by Surface HF Plasma Actuator

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Lift and Drag Control of NACA 23012 Airfoil Model by Surface HF Plasma Actuator

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This paper presents investigation of pulse periodic surface high frequency discharge influence on drag and lift coefficient of NACA 23012 Airfoil Model. Current experimental research is an extension of previous work [1]. The results of flow control over NACA 23012 Airfoil Model by surface HF plasma actuator are obtained (V_∞<20 m/c, Re < $2\cdot10^5$). The typical parameters of CHFD used in these experiments are the followings: HF frequency F_{HF}~350 kHz, modulation frequency F_M=10^2-10^4 Hz (Strouhal number St= (F_M D)/V=1.2 ÷ 80), mean HF power N_{HF}< 400W. The angle was changed $0<\alpha<25^0$. It is shown that the discharge has a significant influence on lift (ΔC_L<0.1) and drag force ($0<\Delta C_p<0.4$) at $\alpha = 13^0$. The results were compared with Pitot tube measurements of pressure in wake of Airfoil Model. Parametric studies of the effect are performed. The results are analyzed in terms of the possible discharge action on an unsteady flow separation as the main mechanism. Different mean HF power N_{HF} of discharge are compared and analyzed. It was shown that at N_{HF} > 200W the attachment of flow occurs at all modulation frequencies. Never the less N_{HF} = 200W the reattachment of flow occurs unsteady and stochastically.

Nomenclature

HF = high frequency
CHFD = capacity coupled high frequency discharge
f_{HF} = HF career frequency
F_M = modulation frequency of CHFD
T_i = pulse duration
N_{HF} = mean power input in plasma
M =Mach number
V_∞ = airflow velocity
St^+ = non-dimensional frequency (Strouchal's number)
C_x = drag coefficient
C_y = lift coefficient

Introduction

The separation control by means of barrier discharges are widely studied in recent years. Great attention was paid to dielectric barrier discharges (DBD), operating at frequency of several kHz and creating a near wall jet. Never the less, the efficiency of flow control near a body by a chord-wise dielectric barrier discharge is decreased considerably at high airflow velocity (V_∞>10m/s) because of the physical limitations on the DBD induced momentum, while pressure gradients in the external flow increases with velocity increase [2,3].

The control of leading edge over separation occurring over an airfoil at high angle of attack in the wake of cylinder was studied in [4]. It was shown that lift coefficient increases when plasma actuator is on (cylinder is not in an air tube) or cylinder is in front of the wing (plasma actuator is off). Plasma actuator doesn't give additional increase of lift coefficient while airfoil is in the wake of cylinder model.

The influence of periodic heat at the leading edge of an airfoil is studied in [5]. It was clearly shown, that laser heat on the leading edge induce turbulization of boundary layer (v_∞ = 23 m/s, Re = 2 10^5). The separated flow attachment causes an increase of lift force up to 5,9%. The PIV measurements showed that drag force incises up 520% in shear layer after laser is switched on.

In spite of the wide use of the surface DBD discharges of any frequency range in the aerodynamic studies, up to the moment there is no clear understanding of the prevailing mechanism of the discharge action on a separation process, especially at high oncoming flow velocities. In the discussion, following mechanisms are mainly involved: momentum addition to the flow from the ionic wind, boundary-layer mixing by discharge – generated vortices and loss of stability of the boundary layer due to average or instantaneous heating or periodic forcing.

Experimental setup

Low-velocity (<20m/s) experiments were cared in the aerodynamic channel with 100x100x300 test section, operating in a continuous regime. Flow velocity can be changed by controlling the blower motor. Large-scale flow turbulence after the blower was quenched by honeycomb. However, turbulence level remained high enough (~several percent's) Fig 1.

NACA 23012 airfoil model 8cm x 10cm (chord x span) was manufactured from Nylon-6. Model was positioned in the test section at a desirable attack angle using rotating mechanisms. The electrodes were arranged near the

model's leading edge (Fig. 1), with wiring connected to the mounting points of the model. Discharge region was made of ceramics (BN) to withstand the temperature in the discharge region. Flow blockage was up to 30% at 25^0 attack angle and 10% at 0^0 attack angle.

Discharge was created by "RF switch" generator, loaded with the model through the air-core resonant transformer. Resonance frequency was ~350 kHz. Output voltage was up to 20 kV, the peak discharge power- 1 kW. The generator was operating in the pulse-periodic regime, creating RF pulses with 30-100 us duration and repetition frequency up to 10 kHz. Rise time was about 5 - 10 us. Pulse shape changed with discharge power due to resonant frequency shift during the pulse. These changes weren't controlled in the experiments.

Discharge voltage was measured with Tektronix P6014A HV probe, discharge current was measured in the ground lead with Tektronix AC current shunt. Stray current was negligible due to significant discharge capacity. Electrical power input was calculated by digital multiplication of current and voltage signals via TDS 2014B oscilloscope with ~10% error. Alternatively, energy release over the pulse was measured by an integration on the capacity

Wake structure was studied by an array of 14 0.7 mm diameter Pitot tubes, positioned 0.5-5 diameters downstream from the model, in the middle of its span. The pressure was measured by a 16-channel pressure scanner Esterline 9116 with 500 Hz time resolution.

The scales consisted of 4 tensoresistive sensors (T24A-0,01-C3), dynamic converter (ПД-004), and power supply (АИП-012). The digital signal was processed whit Lab View soft. The limit of force measurement was 10 kg. Accuracy of measurement was δ<0.7%. Time resolution was 0.03 s (30 Hz).

Results

Parametric studies of drag and lift forces coefficient show significant influence of plasma high frequency modulated DBD on airfoil model flow control. The wing profile NACA23012 was fixed at angle of attack from 10 to 30^0. It was found that there is no influence of the HF discharge on drag Cx and C_y lift coefficient of the wing airfoil model unless than the critical angle of attack is more than $\alpha > 13^0$ (fig.5). At the critical angle of attack $\alpha = 13^0$ of the airfoil model C_x is reduced by 40% with increasing of frequency modulation (fig. 2a). When the modulation frequency f_{mod}> 1000Hz impact of the discharge on the C_x goes into saturation. There in no further drag reduction while modulation frequency is increased. C_y increases slightly over the all range of modulation frequencies of discharge (fig. 2c). Maximum increase of C_y reaches 10% in the interval 100< f_{mod} <500Hz. Further increase of modulation frequency leads the C_y decrease to the unperturbed state (f_{mod} > 1000Hz) Generalization parametric dependences C_x and C_y allows to calculate the aerodynamic quality of the current plasma actuator model airfoil. Aerodynamic efficiency increases with increasing f_{mod} and goes into saturation at f_{mod}> 400Hz at the critical angle of attack $\alpha = 13^0$ as it can be seen at fig. 3a. The increase of C_y/ C_x comes up to 62%. It should be mentioned that reducing the discharge pulse power leads to lower influence on flow for all investigated angles of attack. It has been found, that the stochastic process of flow reconnection were observed at 1000< f_{mod} <1500Hz and power of discharge N_{HF} = 100W (pic. 2a,c , pic. 3a,c). One can see on oscillogram, that reattachment occurs only for 2 seconds while switching discharge at the modulation frequency 1040 Hz, and then, in spite of the fact that the dielectric barrier discharge is still on, flow separation occurs. The drag and the lift force returns back to the values of the released state. That is the main reason, why C_x and C_y fluctuate in a sufficiently wide range at the regime of current modulation frequencies and pulse power. The discharge dose not significantly influence on C_x at the angle of attack $\alpha = 20^0$ (pic. 2b). Slight drag decrease (less then 2%) occurs at the modulation frequency f_{mod} - 2000 Hz. At the same time, the lift coefficient of the wing is increased at supercritical regimes $\alpha = 20^0$ (pic. 2d). It should be mentioned that the maximum increase of C_y, occurs at a low frequency modulation (130< f_{mod} <200Hz) and is about 10%. This frequency range is much narrower than in the case of frequency range at a critical angle of attack (α = 13^0). The HF discharge influence on an airfoil flow around aerodynamic model at high supercritical angles of attack seems to be close to the results which were obtained in other bluff bodies, such as the cylinder model [6]. With the increasing of modulation frequency the influence of the discharge on Cy decreases, and at a modulation frequency f_{mod}> 1000Hz lift coefficient of an airfoil is reduced by 2%. Aerodynamic efficiency in the excited state is increased by 9% at a modulation frequency f_{mod} = 250Hz, mainly due to increase of wing model lift (pic. 3b). The average pressure in the wake of the model varies with the HF surface discharge ignition. Frequency dependences of P_{av} (f_{mod}) and C_x (f_{mod}) correlates with each other. (pic. 2a,b, рис. 3 c,d). It has been found that all modulation frequency bands leads to increase of the cross section average total pressure in the wake of an airfoil model. The shift of the separation point in [8] reduces the separation bubble [7-8].

Discussion

The results of experimental studies from previous chapter provide preliminary conclusions of pulsed DBD influence on C_x, C_y, and flow separation of the NACA23012 airfoil model with corresponding Reynolds, Strouhal numbers and angle of attack. Drag reduction occurs as separation point shifts down the surface of the airfoil model. It was shown that there is a flow separation point shift on 1/3 of the wing chord length at modulation frequency of 130 Hz and power N_{HF} = 400W in 14 ms after discharge inclusion [8]. Parametric studies of HF DBD modulation frequency influence on the airfoil aerodynamic characteristics verify these data. It is clearly seen that there is no change in C_x, C_y, P_{av} in regimes whit no flow separation on the wing model $\alpha < 12^0$ at any impulse power supply and

modulation frequencies. The most influence of flow control is at the model location on the critical angle of attack, but never the less there is still ability to control C_x, C_y, P_{av} at high angles of attack.

Possible mechanism of HF DBD plasma influence on boundary layer can be clarified after analysis an airfoil aerodynamics. In a series of experiments the constant pulse power was held in HF DBD. The average discharge energy input increased while frequency modulation was rising up. The modulation frequency increasing (mean power increasing) leads to higher impact of the discharge only for low-frequency modulation regimes. Further on, the energy input (frequency modulation) raise leads to slight changes of C_x, C_y, P_{av}. The main aerodynamic parameters goes into saturation (C_x (f_{mod}), P_{cp} (f_{mod}) at $\alpha = 13^0$) or decreases (C_y (f_{mod}) with $\alpha = 13, 20^0$). Besides all at certain angles of attack ($\alpha = 15, 20^0$), lift decrease and drag increase are observed. At high angles of attack the discharge impact on main aerodynamic characteristics of an airfoil model is said to be close to the one of bluff bodies (cylinder, cone, perpendicular to flow plate). Never the less, no HF DBD modulation frequency were found for current airfoil model to increase drag significantly, as it has been shown for the cylinder model [9].

An additional attention should be paid to regime of not high mean power (N_{HF} =100W). The discharge impact on the flow leads to stochastic unsteady reattachments of the separation flow. It is clearly seen. That there is a threshold frequency in the considered regime (f_{mod}>100Hz, St >5). C_x, C_y, P_{av} oscillate in the range of relevant values for discussed regimes with an average energy between 50 and 400 watts.

Conclusions

The flow control at velocity of 20 m/s by means of HF DBD plasma actuator on the surface on an NACA23012 airfoil model at critical and supercritical angles of attack $\alpha > 12^0$. Subcritical HF DBD actuator flow control at the selected angle of attack apparently does not occur.

Maximum reduction up to 40% of C_x is obtained at $\alpha = 13^0$, f_{mod}> 1000Hz, fig. 2a.

Maximum increase up to 10% of C_y, is obtained at $\alpha = 13^0$, f_{mod}> 200Hz, fig. 2c. Maximum HF discharge impact on the aerodynamic characteristics C_x and C_y occurs in different frequency ranges of modulation frequencies.

It was shown, that there are regimes with unsteady and reattachment of separation flow. (Sh=4-10, $N_{HF} \approx$ 100W, $\alpha = 13^0$).

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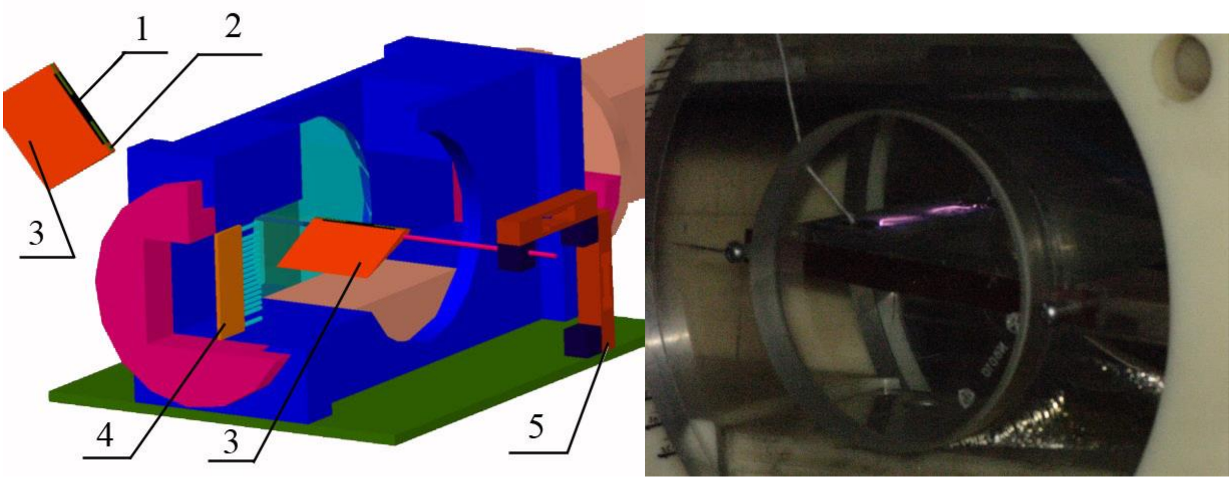
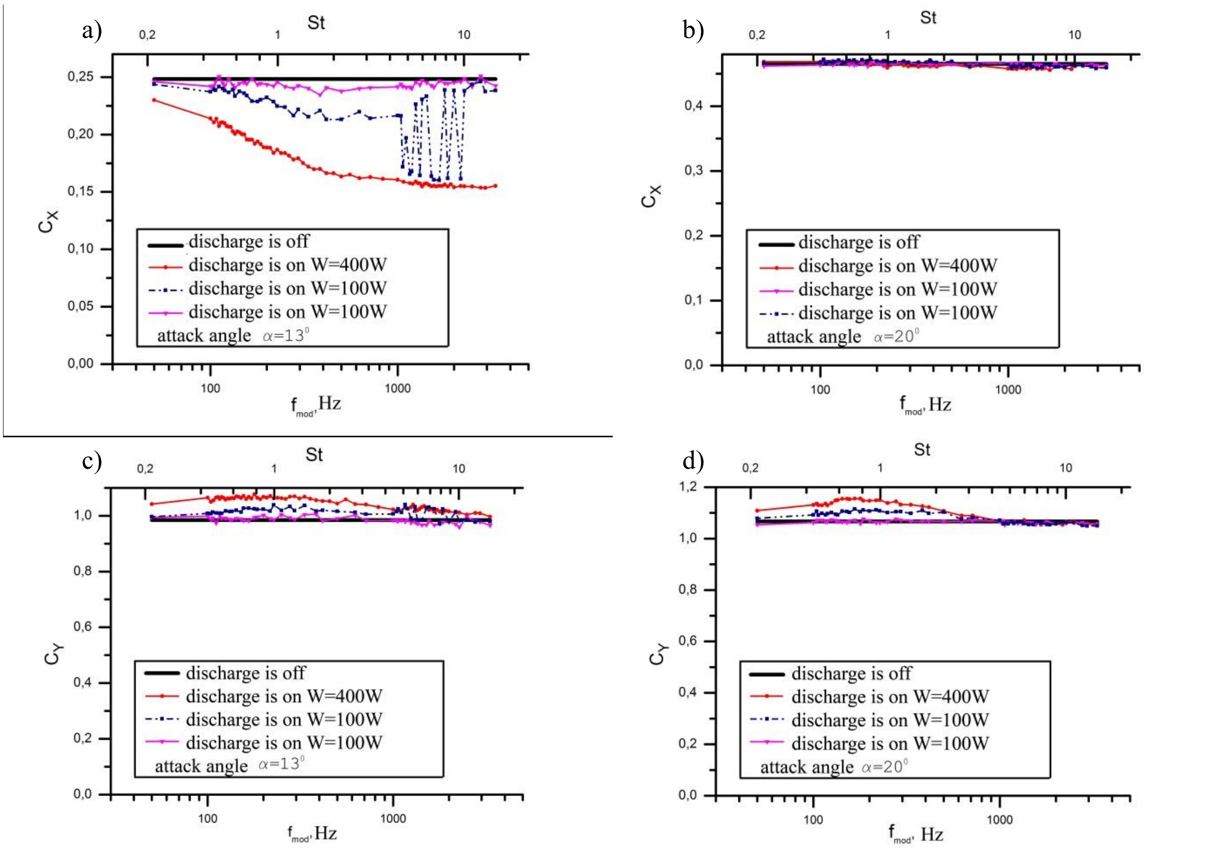
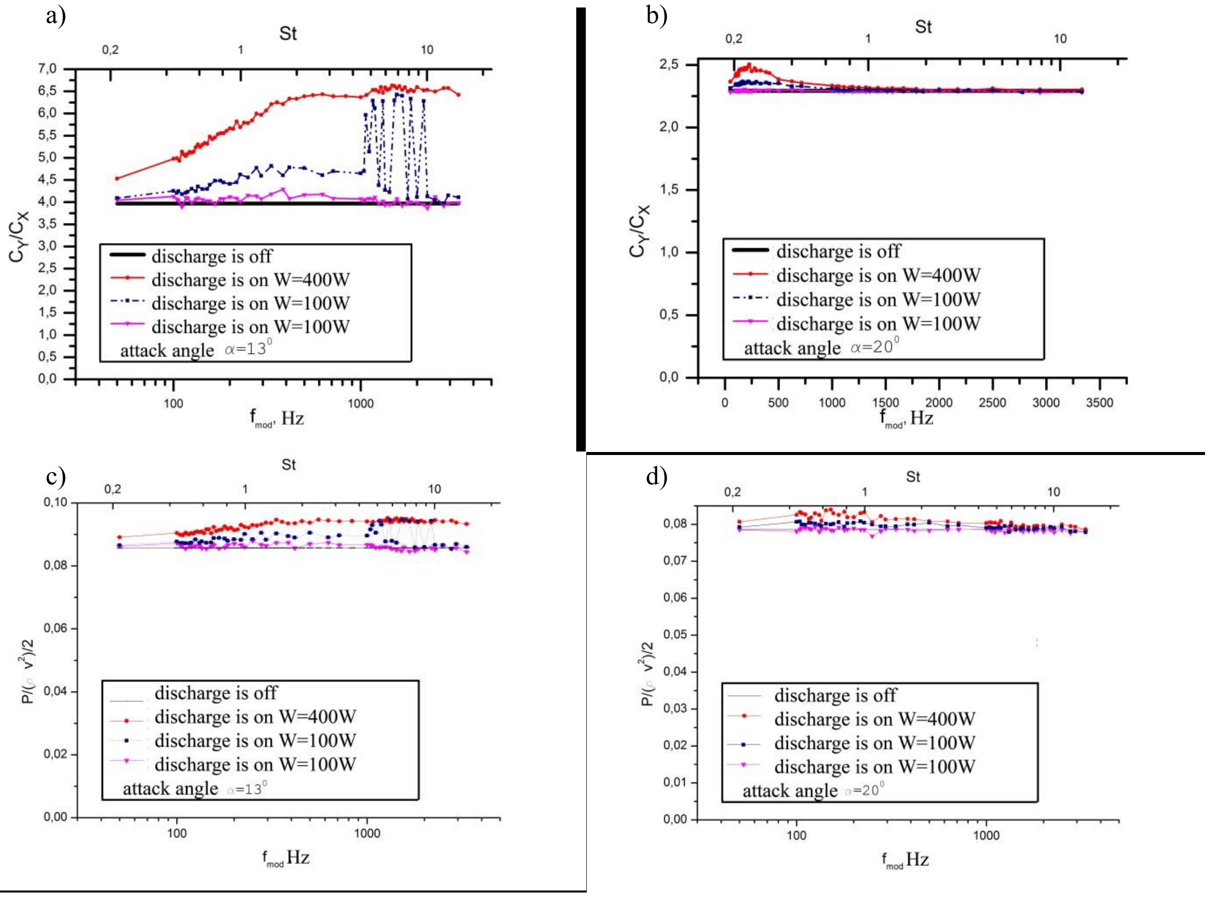


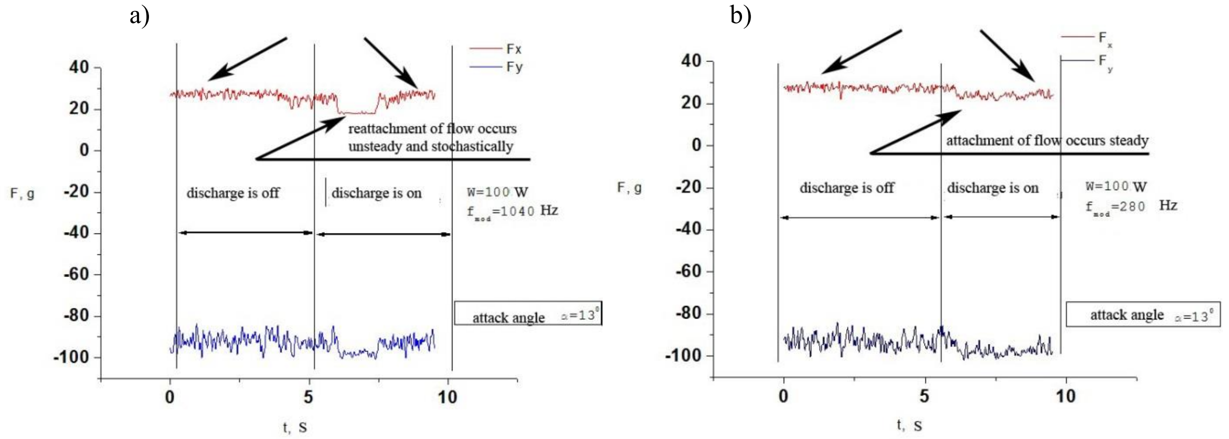
Pic. 1. Main scheme and photo of wind tunnel with of NACA 23012 Airfoil Model inside. The plasma DBD actuator is switched on. 1 – dielectric, 2 – HF electrode, 3 – airfoil model, 4 – Pitot tube, 5 – strain gauge scales.



Pic. 2. Comparison of lift and drag coefficient at different modulation frequencies (Strouhal numbers). a) C_x, $\alpha=13^0$, b) C_x, $\alpha=20^0$, c) C_y, $\alpha=13^0$, d) C_y, $\alpha=20^0$.



Pic. 3. Comparison of fineness and mean pressure in wake flow of the airfoil at different modulation frequencies (Strouhal numbers). a) C_y/C_x, $\alpha=13^0$, b) C_y/C_x, $\alpha=20^0$, c) P_{cp}, $\alpha=13^0$, d) P_{cp}, $\alpha=20^0$.



Pic. 4. The oscillograms of lift and drag forces at different modulation frequencies (Strouhal numbers) of discharge.

Referenses

1. Bluff body aerodynamic wake structure control by a high frequency dielectric barrier discharge. I.A. Moralev, P.N. Kazansky, A.I. Klimov, V.A. Bityurin // The 10 th International Workshop on Magneto-plasma Aerodynamics p. 11 (2011)
2. Limitations of the DBD effects on the external flow //A. V. Likhanskii, M. N. Shneider, D. F. Opaits, R. B. Miles, and S. O. Macheret // 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition 4 – 7 January 2010, Orlando, Florida, 2010
3. Surface plasma induced wall jets // D. F. Opaits, M. R. Edwards, S. H. Zaidi, M. N. Shneider, R. B. Miles, and S. O. Macheret // 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition 4 - 7 January 2010, Orlando, Florida, 2010, no. January.
4. Flow Control of a NACA0015 Airfoil in a Turbulent Wake Using Plasma Actuators // Rasool Erfani_, Craig Haleyand Konstantinos Kontisz // The University of Manchester, Aero-Physics and Advance Measurement Technology Laboratory, Sackville Street, Manchester, M60 1QD, United Kingdom, AIAA 2012-0187

5. N. Tichenor, A. Bright, K. Kremeyer, M. Lenzner, J. Yeak, R. Wlezien. Experimental Investigation of Laser-Based Flow Modification Over a Low Speed Airfoil // 51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition 07 - 10 January 2013, Grapevine (Dallas/Ft. Worth Region), Texas, AIAA 2013-0903.
6 Klimov, I.A. Moralev, V.A. Bityurin, P.N. Kazansky, Boichov C.J. Lift and drag control of circular cylinder by surface hf plasma actuator. 51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition. 07-10 January 2013, Grapevin (Dallas/Ft Worth Region), Texas, AIAA 2013-0753.
7 Klimov, I.A. Moralev, P.N. Kazansky. Influence of HF DBD on aerodynamic drag of an airfoil model// Electronics, electrical engineering and energy. Eighteenth International scientific and technical conference of students and postgraduate students. p. 37 (2012).
8 Klimov, I.A. Moralev, V.A. Bityurin, P.N. Kazansky. Flow Control over NACA 23012 Airfoil Model by Surface HF Plasma Actuator // 50th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, 09 - 12 January 2012, Nashville, Tennessee, AIAA 2012-1031.
9 P.N. Kazansky. Flow control near aerodynamic bodies by means of high-frequency plasma actuator: PhD thesis: specialty 01.04.14 – Moscow., 2013. – 160c.